Hybrid MOND-dark matter models confronted with weak lensing data

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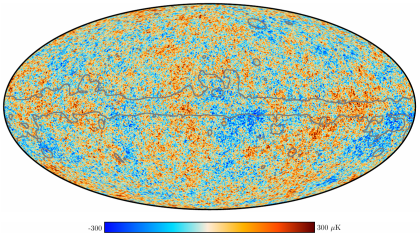
Why hybrid models?

Dark matter: Cosmological scales

Structure of anisotropies



[Planck Collaboration 2018]

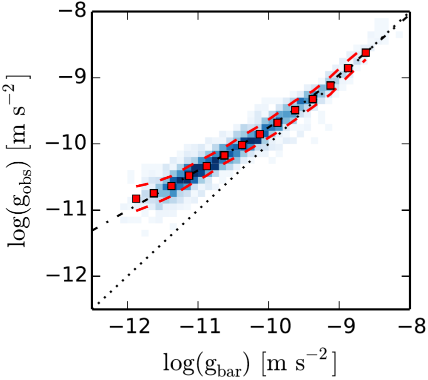
↓

Collisionless fluid

Cold Dark Matter (CDM)

MOND: Galactic scales

Dark matter $\leftrightarrow$ normal matter



[Lelli et al 2017]

↓

Modified force law

with $a_{\rm bar} \to \sqrt{a_0\, a_{\rm bar}} \sim \frac{\sqrt{GM_b a_0}}{r}$

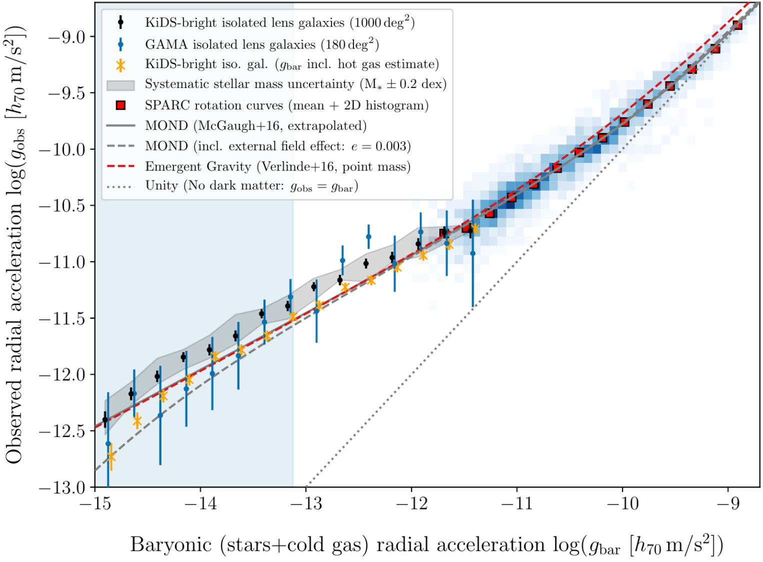
Hybrid models

νHDM, dipolar dark matter, Aether Scalar Tensor Theory, Superfluid dark matter, ...

Example: νHDM

Galaxies	**CMB/Cosmology**
MOND	no MOND
$+$	$+$
negligible ρ_ν	significant ρ_ν

Weak lensing



[Brouwer et al 2021]

Aether Scalar Tensor Theory (AeST)

[TM, McGaugh, Hossenfelder, arXiv:2301.03499, under review]

AeST: Structure of equations around galaxies

In spherical symmetry*:

$$\Delta\hat{\Phi} = 4\pi G_N f_G(\rho_b + \rho_c)\,,$$

$$\vec{\nabla}\left(\tilde{\mu}\left(\frac{|\vec{\nabla}\varphi|}{a_0}\right)\vec{\nabla}\varphi\right) = 4\pi G_N f_G(\rho_b + \rho_c)\,.$$

Acceleration inferred from kinematics (e.g. rotation curves):

$$\vec{a}_{\rm tot} = -\vec{\nabla}(\hat{\Phi} + \varphi)$$

Acceleration inferred from lensing:

$$\vec{a}_{\rm tot} = -\vec{\nabla}(\hat{\Phi} + \varphi)$$

*****[TM, arXiv:2305.07742]*

AeST: Condensate density

$$\rho_c = \frac{m^2}{4\pi G_N f_G}\left(\frac{\dot{\varphi}}{Q_0} - \hat{\Phi} - \varphi\right)$$

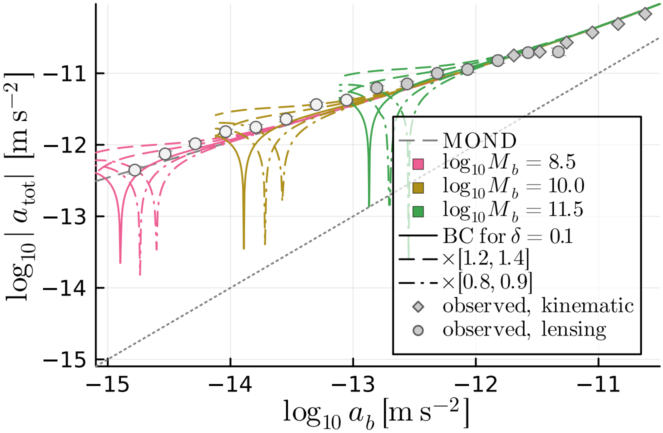
- Choice of "integration constant" is physical
- Interpretation: Chemical potential of condensate

$\rightarrow$ Unlike MOND: To solve equations, need ρ_b + chemical potential

[NB: m^2 is called μ^2 in Skordis et al. 2021]

AeST: Effect of condensate density

Deviations from MOND at large radii, depending on M_b and boundary condition (chemical potential)



Assumes $m^2/f_G \approx \mathrm{Mpc}^{-2}$. Can we make this smaller so ρ_c is smaller?

AeST: Rough constraint on m^2/f_G

The m^2/f_G an $M_b = 10^{11}\,M_\odot$ galaxy needs to stay within 10% of the MOND-predicted acceleration at the a_b probed by weak lensing, assuming best-case boundary conditions

Bound on m^2/f_G	Description
$\lesssim 1\,\mathrm{Mpc}^{-2}$	Galaxies, weak lensing ($a_b \geq 10^{-13}\,\mathrm{m/s^2}$)
$\lesssim 0.001\,\mathrm{Mpc}^{-2}$	Galaxies, weak lensing ($a_b \geq 10^{-15}\,\mathrm{m/s^2}$)

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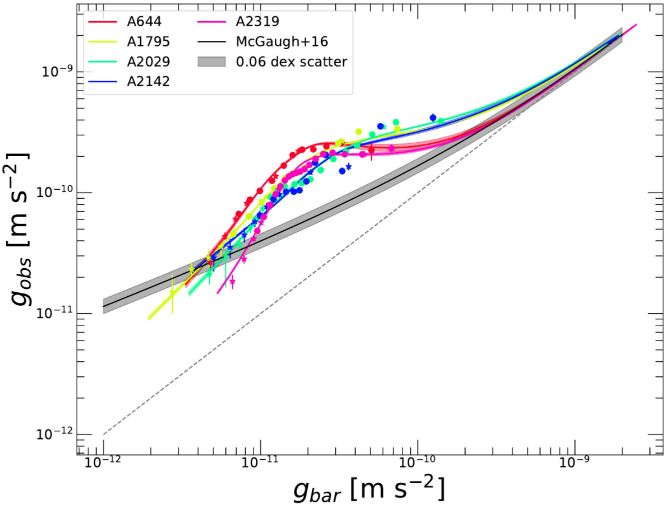
⚠ Then in galaxies, typical condensate density is $\sim 0.01\rho_{\mathrm{crit}}$

Also, galaxy clusters...

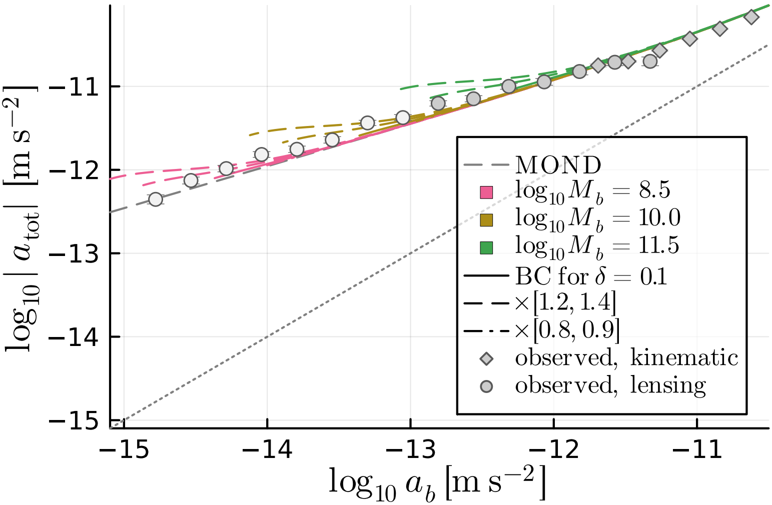
Same kind of argument, now *demanding* deviations from MOND for clusters → Probably need $m^2/f_G \gtrsim \mathrm{Mpc}^{-2}$



[Eckert et al 2022]

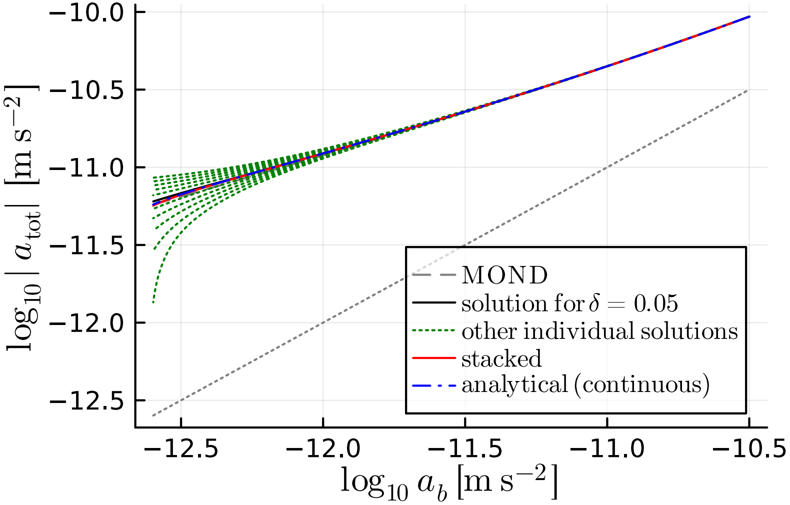
Caveat: Negative densities

Usually unstable, need different form of equations/Lagrangian.



Caveat: Weak lensing data is stacked

Can hide MOND deviations. But need special boundary conditions.



Model-independent argument

Or why that shouldn't be surprising

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$\lightning$

Weak lensing reaches $\sim \mathrm{Mpc}$, does *not* see such deviations

Conclusion

- AeST: Likely tension between weak lensing and galaxy clusters...
- ...but there are some caveats (negative densities, boundary conditions, cluster analysis)
- Model-independent arguments suggest weak-lensing data is challenging for all hybrid models